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SURVEY OF FLUE GAS DESULFURIZATION SYSTEMS. CHOLLA POWER GENERATING STATION, ARIZONA PUBLIC SERVICE COMPANY

Gerald A. Isaacs, et al

PEDCo-Environmental Specialists, Incorporated

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SURVEY OF FLUE GAS DESULFURIZATION SYSTEMS

NEVADA POWER GENERATING STATION, ARIZONA PUBLIC SERVICE COMPANY

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16. ABSTRACT The report gives results of a survey of a wet limestone system for desulfurization of flue gas on Unit 1 of the Cholla Power Generating Station of Arizona Public Service Company (APSCo). This base-load unit has a maximum continuous net generating capacity of 115 MW. At capacity, the boiler burns 54 tons of pulverized coal per hour. The typical gross heat content of the coal, as received, is 10,290 Btu per pound; typical ash and sulfur contents are 10.4 and 0.55 percent, respectively. The system consists of two parallel scrubbing train modules, each accommodating 50 percent of the flue gas. Both modules include an adjustable flooded-disc scrubber for particulate control, followed by a tower. The module A tower is packed, utilizing a limestone slurry for SO2 removal. The module B tower contains no packing, and limestone is not circulated through it. APSCo estimates module B SO2 removal efficiency to be 25 percent. The system operates in an open-loop mode, since there is no recycling of liquor from the fly ash pond. Approximately 386 gallons of make-up water are required per pound-mole of SO2 removed. Installed cost for the system is reported to be about $6.5 million, or $57 per KW. Annualized costs are estimated to be 2.2 mills/KWHr, including a 23 percent charge on capital investment to account for interest, depreciation, taxes, and other fixed charges.

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June 1975

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SUMMARY

A wet limestone system was designed and installed by Research-Cottrell for desulfurization of flue gas on Unit 1 of the Cholla Power Generating Station of Arizona Public Service Company. This is a base-load unit with a maximum continuous net generating capacity of 115 MW. The boiler burns 54 tons per hour of pulverized coal at capacity. The typical gross heat content of the coal, as-received, is 10,290 BTU per pound; typical ash and sulfur contents are 10.4 and 0.55 percent, respectively.

The flue gas desulfurization system consists of two parallel scrubbing train modules, each designed to accommodate 50 percent of the flue gas. Module A of the system includes an adjustable flooded-disc scrubber for particulate control followed by a packed tower which utilizes a limestone slurry for SO_2 removal. Module B also incorporates a flooded-disc scrubber for particulate control. Its second stage absorber shell is similar to that for Module A, but it contains no packing, and limestone slurry is not circulated through it. SO_2 removal efficiency for Module B is estimated by Arizona Public Service to be 25 percent.

Testing of the system started on October 2, 1973, and continued until a scheduled shutdown on October 21. Research-

Cottrell reported that Module A collection efficiencies for particulates and SO_2 during that test run were 99.7 percent and 92 percent, respectively. System availability was reported to exceed 92 percent. Official acceptance tests for the system have not been performed by Arizona Public Service, as of April 30, 1975.

After minor modifications the system was officially started on December 14th and operated with a 92.6 percent availability factor until April 15th when it was again brought down for scheduled modifications of the expansion joints. Repair crews, supplied by Research-Cottrell, were available during most of the first half of 1974. Their attention to the maintenance of the units partly accounted for the high availability that was demonstrated during this shakedown effort. Modifications were completed by the end of April, and the system has continued to operate with high reliability since that time.

The system operates in an open-loop mode, since there is no recycling of liquor from the fly ash pond. Approximately 386 gallons of make-up water are required per pound-mole of SO_2 removed.

Installed cost for the flue gas desulfurization system is reported to be about $6.5 million, or $57 per KW. Annualized costs are estimated to be 2.2 mills/KWH. This figure includes a 23 percent charge on capital investment to account for interest, depreciation, taxes and other fixed charges.

On December 25, 1974, Research-Cottrell was awarded a contract for the installation of a similar system on Cholla Unit 2, where the boiler is under construction. When this unit is completed, the plant will have 365 MW of capacity with SO_2 controls.

Pertinent data on Unit 1 and on the system operation are summarized in the following table.

SUMMARY OF FGD DATA, CHOLLA UNIT NO. 1

Unit rating (net), MW	115
Fuel	Coal
Gross heating value, BTU/lb (typ)	10,290
Ash, percent (typ)	10.4
Sulfur, percent (typ)	0.55
FGD vendor	Research-Cottrell, Inc.
Process	Wet limestone scrubbing
New or retrofit	Retrofit
Start-up date	October 1973
FGD modules	2 - Only one has packing and limestone circulation
Efficiency, percent	
Particulates	99.7 - vendor data
SO_2	92 - Module A - (vendor data) 25 - Module B - (utility estimate)
Water make-up, gallons/lb-mole SO_2	386[a]
Sludge disposal	Unstabilized sludge disposal in unlined pond. Temporary solution only.
Unit cost, 1973 dollars	6.5×10^6 (no limestone grinding or sludge treatment facilities exist).

[a] Calculated value assuming overall SO_2 removal efficiency of (92 + 25)/2 = 58.5%

1.0 INTRODUCTION

The Control Systems Laboratory of the U.S. Environmental Protection Agency (EPA) has initiated a study to evaluate the status of selected flue gas desulfurization (FGD) systems on coal-fired boilers in the United States. This report on the Cholla Power Generating Station of Arizona Public Service Company (APS) is one of a series of reports on such systems. It presents values of key process design and operating parameters, describes the major start-up and operational problems encountered at the facility and the measures taken to alleviate such problems, and identifies the total installed capital costs and annualized costs.

This report is based upon information obtained during a plant inspection on April 2, 1974, and on data provided by personnel of APS and Research-Cottrell, Inc. (R-C).

Section 2.0 presents pertinent data on facility design and operation, including actual and allowable particulate and SO_2 emission rates. Section 3.0 describes the FGD system and Section 4.0 analyzes FGD system performance. Appendices present details of plant and system operation and photographs of the installation.

2.0 FACILITY DESCRIPTION

2.1 PLANT LOCATION

The Cholla Power Generating Station of APS is located near Joseph City, in Navajo County, Arizona. The terrain around the Cholla Station is relatively flat and practically arid; there is no major industry in the area. The nearest sizable populated area is the town of Holbrook, about 10 miles east of the plant.

2.2 BOILER DATA

At present Cholla operates only Unit 1, having a dry-bottom, pulverized-coal-fired boiler with a net 115 MW generating capacity. The boiler was designed by Combustion Engineering, Inc. (CE). Plant capacity will increase to 365 MW upon completion of Cholla Unit 2, a 250 MW unit that is under construction.

The coal now being burned has typical fuel values, as-received, of 10,290 BTU/lb, 10.4 percent ash and 0.55 percent sulfur.

2.3 POLLUTION CONTROLS

A R-C multicyclone-type collector, operating with an efficiency of about 75 percent, provides primary control of particulate emissions. Design particulate loading at the

outlet of the multicyclones is approximately 2.0 grains per standard cubic foot (gr/scf).

The maximum particulate emission allowed under Arizona State Department of Health Regulation No. 7-1-3.5 is 0.196 lb/MM BTU of heat input to the boiler. The present atmospheric emission of particulate from Cholla's FGD system is reported by APS to be 0.026 lb/MM BTU.

Atmospheric emission of sulfur dioxide is limited by Regulation No. 7-1-4.2 to 1.0 lb/MM BTU heat input to the boiler. The present SO_2 emission rate from Cholla Unit 1, based on a combined 58.5 percent removal efficiency in the FGD system, is estimated to be 0.36 lb/MM BTU.

APS plans to install an FGD system on Cholla Unit 2, presently under construction. APS recently signed a contract with R-C to purchase a particulate scrubber and an FGD system for that boiler similar to the system on Unit 1. R-C is preparing preliminary engineering designs and plans to use two modules to treat the flue gases from that boiler.

Table 2.1 presents pertinent data on plant design, operation, and atmospheric emissions.

Table 2.1 PERTINENT DATA ON PLANT DESIGN, OPERATION, AND ATMOSPERIC EMISSIONS

Boiler Data	1	2[a]
Rated generating capacity, MW	115	250
Average capacity factor (1973)	-	-
Served by stack No.	1	-
Boiler manufacturer	CE	CE
Year placed in service	1962	-
Max. coal consumption, T/hr	54	-
Max. heat input, MM BTU/hr	1,112	-
Stack height, ft above grade	250	-
Flue gas rate-max., acfm	520,000	-
Flue gas temperature, °F	276	-
Emission controls		
Particulate	multicylones venturi scrubber	-
SO_2	venturi scrubber absorber tower	-
Particulate emission rate		
Allowable, lb/MM BTU	0.196	0.167
Actual, lb/MM BTU	0.026	-
SO_2 emission rate		
Allowable, lb/MM BTU	1.0	0.8
Actual, lb/MM BTU	0.5 (est.)	-

[a] Boiler under construction. Contract signed with Research-Cottrell to install a particulate control and FGD system.

3.0 FLUE GAS DESULFURIZATION SYSTEM

3.1 PROCESS DESCRIPTION

The FGD system consists of two scrubbing trains, labeled A and B as shown in Figure 3.1, each with a venturi scrubber for particulate emission control and an absorber tower for SO_2 control. However, the absorber B-side tower is not packed and limestone slurry is not circulated through it. Each train treats about half of the total flue gas from the coal-fired boiler or about 260,000 acfm at 276°F. Flue gas from the boiler induced-draft fans is pressurized by two booster fans to a static pressure of about 25 in. H_2O. The flue gas then enters the flooded-disc particulate scrubber and flows downward through the scrubber throat. Limestone slurry flowing out over the disc is atomized as it is sheared by the gas stream at the edge of the disc. Limestone slurry is also injected tangentially through nozzles located on the inside wall of the scrubber shell near the tapered throat. The gas pressure drop and the resulting scrubbing efficiency are regulated by raising or lowering the flooded disc to vary the throat opening. Scrubber components are illustrated in Figure 3.2.

Gas from the particulate scrubber enters the SO_2 absorber near the base of the tower and comes in contact

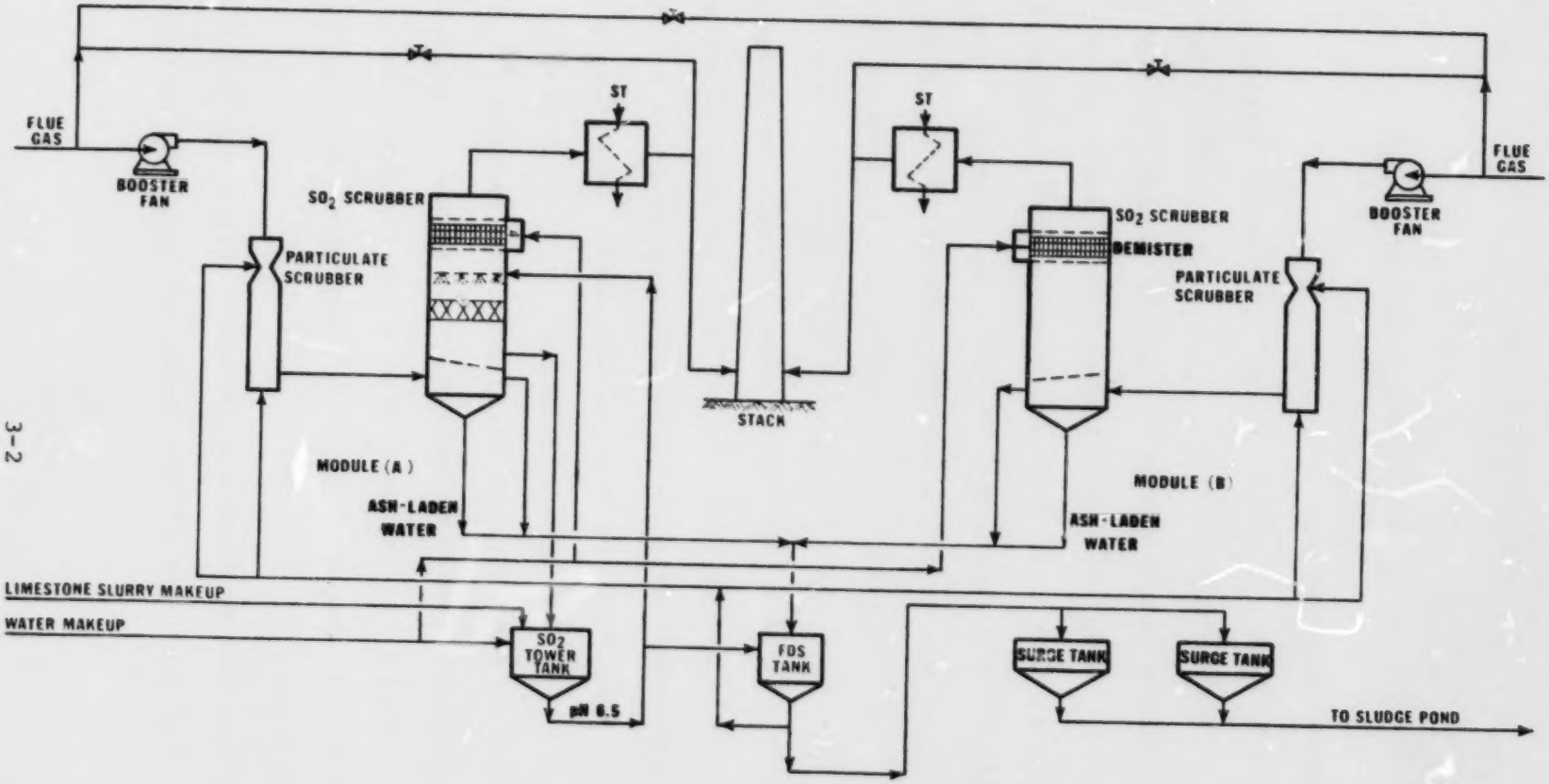


Figure 3.1 Process flow diagram of the FGD system at the Cholla Power Plant.

Figure 3.2 Basic components of Research-Cottrell's FGD system: variable-throat flooded-disc particulate scrubber (foreground) and SO_2 absorber tower (background).

with limestone slurry on the surface of a two-foot-thick fixed packing. The packing is made of corrugated sheets of polypropylene joined in a honeycomb pattern. Only Module A is equipped with this packing. The scrubbed gas then passes through two plastic one-foot-thick demisters, sections of which are washed intermittently with fresh water.

The cleaned flue gas is reheated from 121° to about 165°F as it passes across two bundles of shell-and-tube heat exchangers. The source of heat is high-pressure steam from the boiler steam drum, which is reduced from 1900 psig to 250 psig. The reheated gas then exits through a brick-lined concrete stack, which is common to both trains. The two trains also share a common SO_2 absorber tower recirculation tank.

The rate of limestone addition to the FGD system is about 110 percent of the stoichiometric rate for reaction with the sulfur dioxide in the stack gas. Part of the circulated liquor in the SO_2 absorber is diverted to the flooded-disc scrubber tank (common to both trains) to maintain the pH between 6 and 7 in the particulate control system. The liquid level in this tank is maintained by pumping the excess spent liquor to one of two surge tanks before it is discharged to the fly ash pond.

The plant has no equipment for sludge treatment or fixation. Because of light rainfall and a high evaporation rate in this area no liquor is recirculated from the pond.

The B-side train can be bypassed in conjunction with A-side operation, or both trains can be bypassed simultaneously. However, it is not possible to bypass the A-side train alone, except for short periods of time. This is because limestone enters the system via the A-side absorber and is used to control the operating pH of the entire particulate scrubber system. The inlets to both trains from the booster fans are interconnected through a common suction header, which makes it possible to equalize the gas load to the two trains.

3.2 LIMESTONE MILLING FACILITIES

Ground limestone for the FGD system is purchased from two suppliers, both located in Arizona. The APS limestone specification calls for material that is at least 75 percent by weight less than 200 mesh. Specified minimum CaO is 52.5 percent; specified maximum MgO is 2 percent.

Because the plant has no limestone milling facility, the finely ground limestone is stored in a silo. A small limestone slurry mixing tank is provided at the base of the tower. Limestone milling facilities may be installed after installation of the FGD system on Unit 2.

3.3 PROCESS INSTRUMENTATION

Instrumentation of the FGD installation is housed in two separate areas. Most of the recording instruments are mounted on a panel located in the electrical switch gear building adjacent to the FGD structure. The remaining instruments, primarily for remote control of process op-

erations, are housed in the main boiler control room and are monitored by the boiler control operator.

3.4 DESIGN PARAMETERS

The FGD system at the Cholla Station was designed by R-C to process 480,000 acfm of flue gas at 276°F. The actual total flow to both FGD trains, at 115 MW generating capacity is 400,000 acfm, with about 17,000 acfm of bypass leakage around the FGD system.

Each flooded-disc particulate scrubber operates with a liquid recirculation rate of about 2170 gpm at full load. This represents a liquid-to-gas ratio (L/G) of 10.1 gallons of water per 1000 actual cubic feet (acf) of gas at 122°F. Two-thirds of this liquid is introduced into the scrubber through the hollow shaft of the flooded disc and the remainder is sprayed through tangential nozzles on the vessel wall.

The sulfur dioxide absorber tower operates with an L/G of about 49 gallons/1000 acf. The design gas velocity through the tower is 7.7 feet per second.

Each tower demister is divided into four sections. Each section is sprayed sequentially with process water for 12 seconds every 8 minutes. Flow rate of the process water spray is about 240 gpm.

The shell-and-tube reheater on each train consists of two bundles. The reheater duty is about 8 MM BTU/hr. Six steam operated soot blowers for cleaning of the reheater tubes are operated for 5 minutes during each 8-hour shift.

Tables 3.1, 3.2, and 3.3 summarize operating design parameters and specifications for major components of the FGD system.

3.3 INSTALLATION SCHEDULE

Work on the FGD system at the Cholla Station was initiated in January 1971. R-C, who already had a pilot plant in operation at the Cholla Station and was treating a slip stream from Boiler 1, made a preliminary design and submitted a proposal for the FGD system in April 1971. APS awarded the contract to R-C in July 1971. Construction and initial testing of the system were completed on December 3, 1973, and commercial operation began December 14, 1973.

System installation was delayed for several reasons, including engineering design changes, material specification changes, equipment delivery delays, adverse weather conditions, and system shakedown problems.

3.6 COST DATA

The installed cost of this FGD system to APS was about $6.5 million (equivalent to $57/net KW). This figure, however, does not include the cost of such items as limestone storage and milling facilities and sludge disposal (the present ash pond is used). Additional costs incurred by R-C have not been reported.

Cost of the ground limestone is $19.20 to $23.50 per ton, delivered; transportation cost is $7.07 to $15.58 per ton, ranging from 37 to 66 percent of the delivered limestone cost.

Table 3.1 DATA SUMMARY: PARTICULATE AND SO_2 SCRUBBERS

	Flooded-disc scrubber	SO_2 absorber tower
L/G ratio, gallons/1000 acf	10.1	48.9
Superficial gas velocity, ft/sec		Design 7.7/Actual 6.9
Equipment sizes	6 ft dia. x 45 ft[a]	22 ft dia. x 70 ft[a]
Equipment internals	adjustable disc	2 ft fixed matrix packing

[a] Estimated

Table 3.2 DATA SUMMARY: FGD SYSTEM HOLD TANKS

	Flooded disc scrubber holdup tank	SO_2 absorber towers holdup tank	FGD system sludge holdup tank	Limestone slurry makeup tank
Total number of tanks	1	1 (common)	2	1
Tank sizes	12 ft 6 in. dia. x 14 ft 6 in.	27 ft 4 in. dia. x 28 ft	18 ft 6 in. dia. x 27 ft	
Retention time at full load	7 min.	5 min.	14 hr ea.	-
Temperature, °F	121	121	121	90
pH	5.2	6.5	5.2	
Solids concentration, %	15.5	8.3	25	20
Specific gravity	1.102	1.049		

Table 3.3 TYPICAL PRESSURE DROP ACROSS COMPONENTS OF PARTICULATE SCRUBBER AND FGD SYSTEM

Equipment	Pressure drop, inches W.G.
Flooded-disc scrubber	10
SO_2 scrubber tower	0.5
Demister	0.5
Reheater	3.3
Ductwork	4.35
Total system (particulate & SO_2 removal)	20

Annualized cost for the system is estimated to be 2.2 mills/KWH. This figure includes a 23 percent charge on capital investment to account for interest, depreciation, taxes and other fixed charges.

4.0 FGD SYSTEM PERFORMANCE

4.1 PERFORMANCE TEST RUN

Initial testing of the FGD system began on October 2, 1973. The system operated until the scheduled shutdown date of October 21. During the 3-week test period, particulate and SO_2 removal efficiencies, mist carryover from the towers, maximum process gas flow rates, and bypass gas leakage rates were determined.

Module A consists of a flooded-disc scrubber followed by a packed tower. Vendor data indicated an SO_2 removal efficiency of 92 percent with average inlet and outlet SO_2 concentrations of 417 and 34 ppm, respectively. APS estimates that the SO_2 removal efficiency for Module B is 25 percent. Thus the estimated combined SO_2 efficiency for the two modules is 58.5 percent.

Mist carryover from Modules A and B was nil. The solids carryover, detected as calcium ion, averaged 0.005 gr/scf from Module A. The appearance of the demisters at shutdown on October 21, 1973, and the carryover tests indicated very little entrainment of slurry. Pressure drop buildup across the demister was less than 0.7 in. H_2O over a 4-month period of operation.

The maximum average inlet gas rates during the 3-week operation were 214,300 acfm to Module A and 204,600 acfm to

Module B, with 18,400 acfm air leakage into the system downstream of the flooded-disc scrubbers.

Chloride ion concentrations in the flooded-disc scrubber recirculation and in tower slurries were 1600 and 575 ppm, respectively. These levels are sufficient to cause pitting corrosion in localized areas with temperatures greater than 140°F and pH less than 3.0. The chloride content of the coal ranges between 0.01 to 0.04 percent (equivalent to 8 to 32 ppm by weight in the flue gas). The chloride ion concentration in the boiler water blowdown which is used as make-up water to the FGD unit is 933 ppm. The chloride ion concentration in the well water, used for boiler make-up water, is 144 ppm.

Additional vendor data on the 3-week initial operation are presented in Appendix C.

The FGD system performed satisfactorily from December 15, 1973, to April 15, 1974. Although several upsets caused shutdown of one or both modules for short periods, system availability averaged 92.6 percent during that period.

The FGD units were shut down for short periods in April to replace corroded Corten steel expansion joints on the reheater bundles. Module B was down from April 15 until April 28; Module A was down from April 17 until April 27.

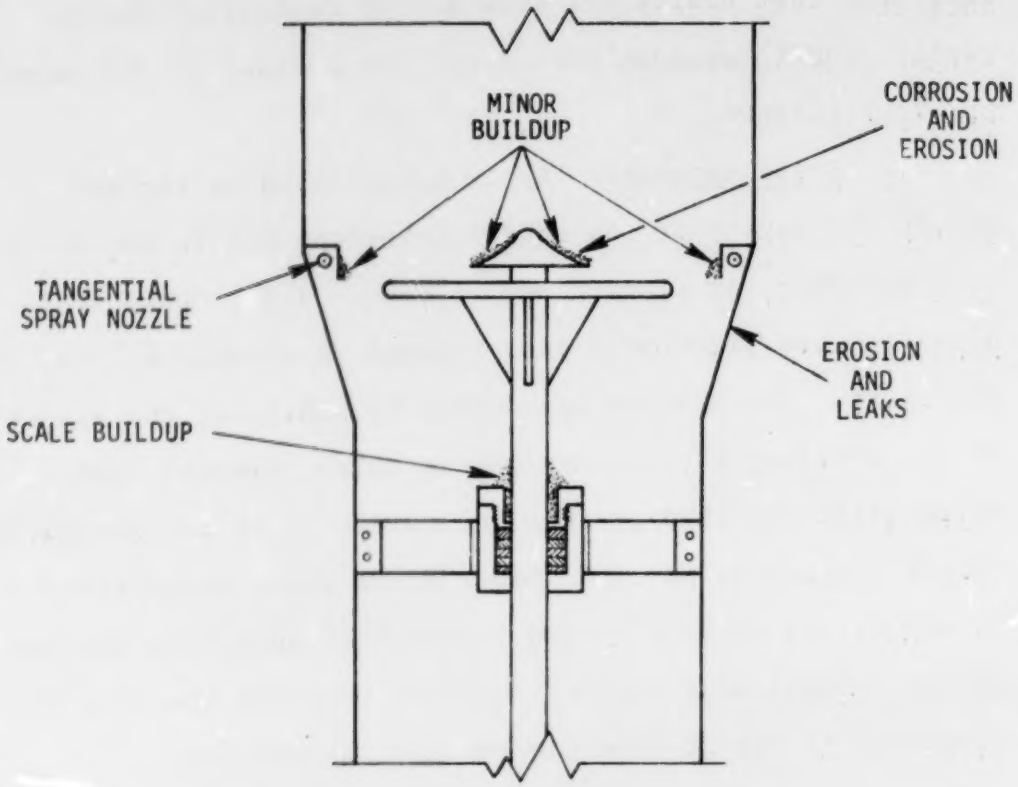
As of March 1, 1975 the FGD system has operated satisfactorily for 14 months with an average availability factor of about 92 percent for each module.

4.2 START-UP PROBLEMS, SOLUTIONS AND COST

An analysis of the problems encountered during start-up indicates that nearly all were due to mechanical design rather than to process chemistry. An account of the major problems follows.

1. Scale deposits: Scale accumulated on top and inside the cavity of the shaft's stuffing box in the flooded-disc scrubber, as illustrated in Figure 4.1. These scale deposits were discovered early enough to prevent binding of the shaft. The problem was solved by modifying the assembly of the stuffing box; it was disassembled, cleaned, and reinstalled inverted so that the cavity is at the bottom and cannot accumulate solids. Other minor scale accumulations on top of the shaft dome and around the tangential nozzles of the flooded-disc scrubber did not obstruct the flow of limestone slurry or flue gas through the scrubber.

2. Corrosion: The expansion joints above the reheaters of Modules A and B were corroded by the weak sulfurous acid condensate. Corrosion was also observed on the top row of tubes near the tube sheet on Module B. The cause in all cases was the accumulation of weak acid condensate in stagnant pockets in the reheater and ductwork. To prevent recurrence of this problem, the ductwork upstream of the reheaters on Modules A and B was insulated and the Corten steel expansion joints were replaced with rubber expansion joints. Also, to prevent acid condensate from reaching the tubes, a trough was installed to divert any condensate from the tube bun-



PROBLEM: SCALE BUILDUP AROUND FDS SHAFT STUFFING BOX. COULD FREEZE SHAFT MOVEMENT.

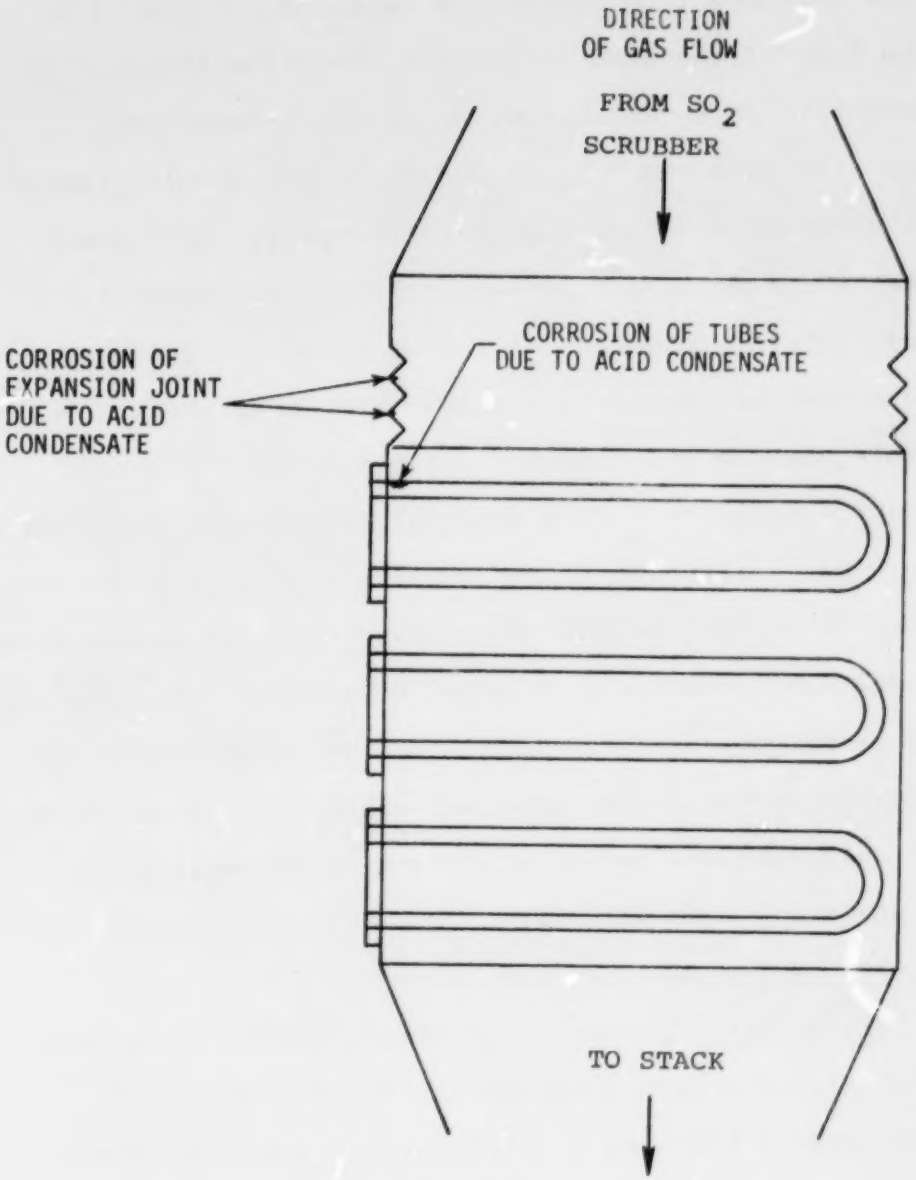
SOLUTION: STUFFING BOX REINSTALLED IN INVERTED POSITION.

Figure 4.1 Scale buildup, erosion and corrosion in the flooded disc scrubber.

dles. The corroded tube bundle was replaced. Figure 4.2 shows the site of the acid condensate corrosion attack. It is important to note that corrosion of the reheater by sulfurous acid occurred only in Module B (the module without packing) which has low SO_2 removal efficiency. Presumably the higher SO_2 removal efficiency of the packed tower precludes significant formation of sulfurous acid. Evidence of chloride attack was noted in the absorber tower shell. To remedy this problem R-C coated the interior of the vessel with an epoxy material. This material eroded away below the scrubber disc. Alternate lining materials such as brick and rubber are being considered. The spray distribution cap above the flooded disc eroded and corroded completely off. The cap is being redesigned by R-C. Additional chloride attack has been observed on the B-side reheater tubes. It is believed that the chlorides are being introduced in the well water used in preparing make-up slurry. The chloride contents of the coal and of the flue gas are extremely low.

3. Vibrations: Harmonic vibrations with deflections of as much as 0.040 inch occurred in the reheaters. The vibrations were attributed to inadequate transition of duct size from the absorber outlet to the reheater shell, with a resultant vortex effect. To remedy the situation, cross baffles were installed at the entrance to the reheater.

Vibrations also occurred in the booster fan on Module B. The vibration was caused by uneven buildup of scale on the fan blades while the unit was idle. The blades were sandblasted, cleaned, and rebalanced.



PROBLEM: CORROSION DUE TO ACID CONDENSATE

SOLUTION: 1) REPLACEMENT OF CORTEN STEEL EXPANSION JOINTS WITH RUBBER EXPANSION JOINTS.

2) INSULATION OF DUCTWORK UPSTREAM OF REHEATER.

3) INSTALLATION OF TROUGH SECTION ABOVE TUBES TO DIVERT ACID AWAY FROM TUBE BUNDLE.

Figure 4.2 Reheater corrosion problem.

4. Miscellaneous problems: Buildup of sediment occurred several times in dead spaces in pipelines and valves of idle pumps and also in process lines during periods of reduced operating rate when slurry velocities in the pipe were low. The solution to this problem was to redesign some pipes to eliminate potential dead pockets. To prevent freezing of valves due to sediment buildup, some valves were repositioned and washout lines were installed.

Some pipe liners eroded. The erosion was due in some cases to unsatisfactory liner materials and in other cases to high velocities through pipes and fittings. Piping modifications helped to reduce the erosion problem. Cracking of the rubber lining in some pipes was due to defects in fabrication.

In recent months while burning low-grade coal having 22 percent ash and 0.7 percent sulfur, some plugging of the tower packing has occurred. It has not yet been verified whether or not this plugging is due to the coal grade. If the buildup of material in the packing continues, it appears that the packing life will be reduced to about six months.

4.3 PROCESS MODIFICATIONS FOR FUTURE INSTALLATIONS

Research-Cottrell, Inc., designer of the wet limestone FGD system at the Cholla Station, indicates no major changes in the design of future installations. Because of reheater tube failures at the Cholla Station however, reheater units in future installations will be fabricated of Incoloy, rather than stainless steel.

APPENDIX A

PLANT SURVEY FORM

PLANT SURVEY FORM[a]

NON-REGENERABLE FGD PROCESSES

A. COMPANY AND PLANT INFORMATION

1. COMPANY NAME Arizona Power Service Co.
2. MAIN OFFICE
3. PLANT MANAGER Cleo Walker
4. PLANT NAME Cholla Power Generating Station
5. PLANT LOCATION Near Joseph City, Arizona
6. PERSON TO CONTACT FOR FURTHER INFORMATION
7. POSITION
8. TELEPHONE NUMBER
9. DATE INFORMATION GATHERED April 2, 1974
10. PARTICIPANTS IN MEETING

	AFFILIATION
James E. McCarthy	Research-Cottrell
George Wilcox	Research-Cottrell
Wade H. Ponder	EPA
Timothy W. Devitt	PEDCo-Environmental
Fouad K. Zada	PEDCo-Environmental

[a] These data were obtained from Research-Cotrell on April 2, 1974. Some of the data have been updated in the text of the report.

B. PLANT DATA. (APPLIES TO ALL BOILERS AT THE PLANT).

	BOILER NO.				
	1	2	3		
CAPACITY, MW	115	Under Construction			
SERVICE (BASE, PEAK)	Base				
FGD SYSTEM USED	Limestone				

C. BOILER DATA. COMPLETE SECTIONS (C) THROUGH (R) FOR EACH BOILER HAVING AN FGD SYSTEM.

1. BOILER IDENTIFICATION NO. 1
2. MAXIMUM CONTINUOUS HEAT INPUT 1112 MM BTU/HR
3. MAXIMUM CONTINUOUS GENERATING CAPACITY 124 MW
4. MAXIMUM CONTINUOUS FLUE GAS RATE, 520,000 ACFM @ 276 °F
5. BOILER MANUFACTURER Combustion Engineering
6. YEAR BOILER PLACED IN SERVICE May 1962
7. BOILER SERVICE (BASE LOAD, PEAK, ETC.) Base
8. STACK HEIGHT 250 ft.
9. BOILER OPERATION HOURS/YEAR (197)
10. BOILER CAPACITY FACTOR *
11. RATIO OF FLY ASH/BOTTOM ASH

* DEFINED AS: $\frac{\text{KwH GENERATED IN YEAR}}{\text{MAX. CONT. GENERATED CAPACITY IN KW x 8760 HR/YR}}$

D. FUEL DATA

1. COAL ANALYSIS (as received)

Dry Basis Avg. as Rec'd.

	MAX.	AVG.
GHV (BTU/LB.)	12146	10290
S %	0.52	0.44
ASH %	12.3	10.4

2. FUEL OIL ANALYSIS (exclude start-up fuel)

GRADE	-	
S %	-	
ASH %	-	

E. ATMOSPHERIC EMISSIONS

1. APPLICABLE EMISSION REGULATIONS

	PARTICULATES	SO_2
a) CURRENT REQUIREMENTS		
AQCR PRIORITY CLASSIFICATION		
REGULATION & SECTION NO.	7-1-3.5	7-1-4.2
MAX. ALLOWABLE EMISSIONS LBS/MM BTU	0.336	1.0
b) FUTURE REQUIREMENTS, COMPLIANCE DATE		
REGULATION & SECTION NO.		
MAXIMUM ALLOWABLE EMISSIONS LBS/MM BTU		

2. PLANT PROGRAM FOR PARTICULATES COMPLIANCE

3. PLANT PROGRAM FOR SO_2 COMPLIANCE

F. PARTICULATE REMOVAL

1. TYPE	MECH. (multiclones)	E.S.P.	FGD Wet limestone
MANUFACTURER	Research-Cottrell	-	Research-Cottrell
EFFICIENCY: DESIGN/ACTUAL	/75	-	98.6/99.2
MAX. EMISSION RATE* LB/HR		-	
GR/SCF	2.0	-	
LB/MMBTU			

DESIGN BASIS, SULFUR CONTENT _____

G. DESULFURIZATION SYSTEM DATA

1. PROCESS NAME wet fly ash/limestone scrubbing

2. LICENSOR/DESIGNER NAME: Research-Cottrell

ADDRESS: Box 750 Bound Brook New Jersey 08805

PERSON TO CONTACT: James E. McCarthy

TELEPHONE NO.: _____

3. ARCHITECTURAL/ENGINEERS, NAME: _____

ADDRESS: _____

PERSON TO CONTACT: _____

TELEPHONE NO.: _____

4. PROJECT CONSTRUCTION SCHEDULE:

	DATE
a) DATE OF PREPARATION OF BIDS SPECS.	January 1971
b) DATE OF REQUEST FOR BIDS	April 1971
c) DATE OF CONTRACT AWARD	July 1971
d) DATE ON SITE CONSTRUCTION BEGAN	
e) DATE ON SITE CONSTRUCTION COMPLETED	December 3, 1973
f) DATE OF INITIAL STARTUP	
g) DATE OF COMPLETION OF SHAKEDOWN	

*At Max. Continuous Capacity

5. LIST MAJOR DELAYS IN CONSTRUCTION SCHEDULE AND CAUSES:

Design changes because of difficulties at Four Corners Plant.

Late equipment deliveries

Material of construction changes

Sub-contract declining job after award

Weather conditions

Start up problems

6. NUMBER OF SO_2 SCRUBBER TRAINS USED two A. has packing B. no packing

7. DESIGN THROUGHPUT PER TRAIN, ACFM @ 276°F 240,000

8. DRAWINGS: 1) PROCESS FLOW DIAGRAM AND MATERIAL BALANCE

2) EQUIPMENT LAYOUT

H. SO_2 SCRUBBING AGENT

1. TYPE limestone purchased in ground form

2. SOURCES OF SUPPLY a) U.S. limestone, Nelson mines, Peach Spring near ~~Kingman, Arizona~~ b) A mine near Tuscan, Ariz.

3. CHEMICAL COMPOSITION (for each source)

SILICATES

SILICA

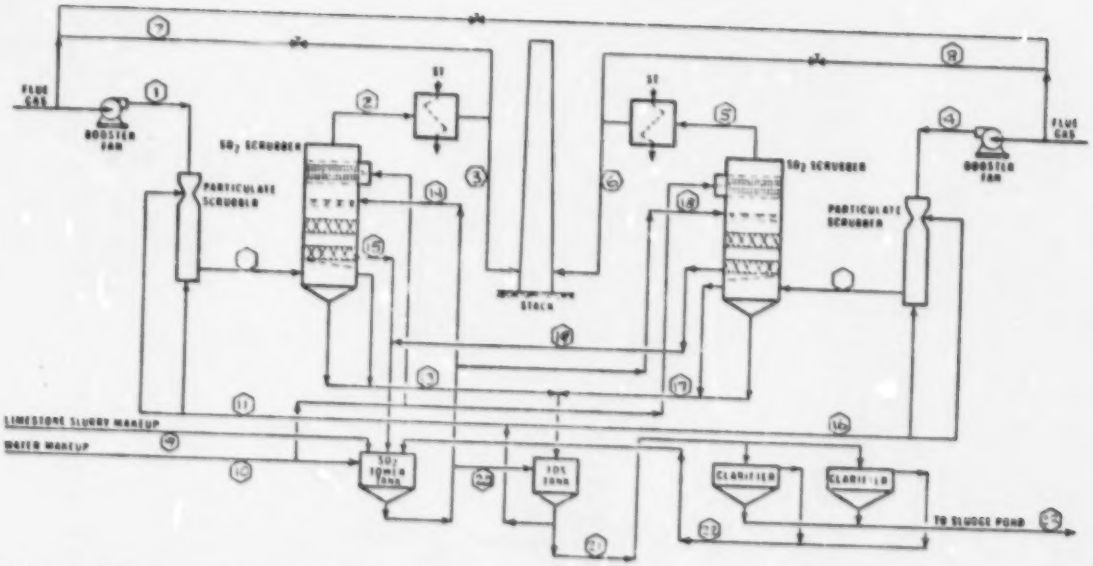
CALCIUM CARBONATE

MAGNESIUM CARBONATE

4. EXCESS SCRUBBING AGENT USED ABOVE STOICHIOMETRIC REQUIREMENTS 10%

5. MAKE-UP WATER POINT OF ADDITION

6. MAKE-UP ALKALI POINT OF ADDITION



STREAM NO	1	2	3	4	5	6	7	8	9	10	11	12	13
RATE, lb/hr													
ACFM	210,000	147,500	183,400	210,000	147,500	183,400		(16,900)					
GPM													
PARTICULATES, lb/hr	2090	102	102	2090	102	102				40	2350		2400
SO_2, lb/hr	556		47	556		280							
TEMPERATURE, °F	278	120	160	278	120	160		(278)			120		
TOTAL SOLIDS, %											7		
SPECIFIC GRAVITY													

STREAM NO	14	15	16	17	18	19	20	21	22	23	24	25	26
RATE, lb/hr													
ACFM													
GPM	10,000	10,520	2350	2400	0	20	32.5	64	0	(64)			
PARTICULATES, lb/hr								3976		3976			
SO_2, lb/hr								785		785			
TEMPERATURE, °F	120		120			120	120						
TOTAL SOLIDS, %	7.5		16				7	16		16			
SPECIFIC GRAVITY													

1. Representative flow rates based on operating data at maximum continuous load.

J. SCRUBBER TRAIN SPECIFICATIONS

1. SCRUBBER NO. 1 (a)

TYPE (TOWER/VENTURI) Flooded disc 2:1 split disc to nozzle

LIQUID/GAS RATIO, G/MCF @ 121 °F 10.1

GAS VELOCITY THROUGH SCRUBBER, FT/SEC

MATERIAL OF CONSTRUCTION

TYPE OF LINING No lining

INTERNALS:

TYPE (FLOATING BED, MARBLE BED, ETC.) flooded disc

NUMBER OF STAGES

TYPE AND SIZE OF PACKING MATERIAL

PACKING THICKNESS PER STAGE (b)

MATERIAL OF CONSTRUCTION, PACKING:

SUPPORTS:

2. SCRUBBER NO. 2 (a)

TYPE (TOWER/VENTURI) Packed Tower, fixed matrix in (A) train, no packing in (B) train

LIQUID/GAS RATIO, G/MCF @ 121 °F 48.9

GAS VELOCITY THROUGH SCRUBBER, FT/SEC Design 7.7/actual 6.9

MATERIAL OF CONSTRUCTION 316L SS

TYPE OF LINING None

INTERNALS:

TYPE (FLOATING BED, MARBLE BED, ETC.) Munters T2-81 Euroform fixed Honeycomb

NUMBER OF STAGES

TYPE AND SIZE OF PACKING MATERIAL Fixed Matrix

a) Scrubber No. 1 is the scrubber that the flue gases first enter. Scrubber 2 (if applicable) follows Scrubber No. 1.

b) For floating bed, packing thickness at rest.

PACKING THICKNESS PER STAGE[b] 2' thick

MATERIAL OF CONSTRUCTION, PACKING: Polypropylene

SUPPORTS: 316L SS

3. CLEAR WATER TRAY (AT TOP OF SCRUBBER)

TYPE None

L/G RATIO

SOURCE OF WATER

4. DEMISTER

TYPE (CHEVRON, ETC.) Plastic polypropylene Primary demister T-271 Secondary demister T-41

NUMBER OF PASSES (STAGES)

SPACE BETWEEN VANES

ANGLE OF VANES

TOTAL DEPTH OF DEMISTER two 1' sections Primary 1" Secondary 1/2"

DIAMETER OF DEMISTER

DISTANCE BETWEEN TOP OF PACKING AND BOTTOM OF DEMISTER

POSITION (HORIZONTAL, VERTICAL) Horizontal

MATERIAL OF CONSTRUCTION Polypropylene

METHOD OF CLEANING Spray top and bottom each quadrant

SOURCE OF WATER AND PRESSURE Process water, 60 psig

FLOW RATE DURING CLEANINGS, GPM 120

FREQUENCY AND DURATION OF CLEANING

REMARKS

5. REHEATER

TYPE (DIRECT, INDIRECT) Shell and tubes

b) For floating bed, packing thickness at rest.

DUTY, MMBTU/HR _____

HEAT TRANSFER SURFACE AREA SQ.FT 3 bundles

TEMPERATURE OF GAS: IN 122°F OUT 182°F

HEATING MEDIUM SOURCE Stepped down and desuperheated 1900 psig steam from steam drum

TEMPERATURE & PRESSURE 2500 psig saturated

FLOW RATE _____ LB/HR

REHEATER TUBES, TYPE AND MATERIAL OF CONSTRUCTION 316L SS

REHEATER LOCATION WITH RESPECT TO DEMISTER 30 ft. horizontal

METHOD OF CLEANING 6 steam soot blowers

FREQUENCY AND DURATION OF CLEANING 5 min. every 8 hrs.

FLOW RATE OF CLEANING MEDIUM _____ LB/HR

REMARKS _____

6. SCRUBBER TRAIN PRESSURE DROP DATA

	Modules A	Modules B
	INCHES OF WATER	
PARTICULATE SCRUBBER	14.75	15
SO_2 SCRUBBER	0.5	0
CLEAR WATER TRAY	-	-
DEMISTER	0.5	0.5
REHEATER	3.3	3.0
DUCTWORK	4.35	4.75
TOTAL FGD SYSTEM	23.4	23.25

7. FRESH WATER MAKE UP FLOW RATES AND POINTS OF ADDITION

TO: DEMISTER _____

QUENCH CHAMBER _____

ALKALI SLURRYING _____

PUMP SEALS _____

OTHER _____

TOTAL _____

FRESH WATER ADDED PER MOLE OF SULFUR REMOVED _____

8. BYPASS SYSTEM

CAN FLUE GAS BE BYPASSED AROUND FGD SYSTEMS _____

GAS LEAKAGE THROUGH BYPASS VALVE, ACFM _____

K. SLURRY DATA

	pH	% Solids	Size	Hold up time
LIME/LIMESTONE SLURRY MAKEUP TANK		varies	2'ø x 4'	
PARTICULATE SCRUBBER EFFLUENT HOLD TANK (a)	5.2	15	12'6" ø x 14'2"	7 min.
SO_2 SCRUBBER EFFLUENT HOLD TANK (a)	6.5	8	27'4" ø x 28'	5 min.

L. LIMESTONE MILLING AND CALCINING FACILITIES: INDICATE BOILERS SERVED BY THIS SYSTEM.

TYPE OF MILL (WET CYCLONE, ETC.) _____

NUMBER OF MILLS none

CAPACITY PER MILL _____ T/HR

RAW MATERIAL MESH SIZE _____

PRODUCT MESH SIZE Received as powder

Note: cost of limestone $18/ton of which $7.74 for transportation

SLURRY CONCENTRATION IN MILL _____

CALCINING AND/OR SLAKING FACILITIES _____

SOURCE OF WATER FOR SLURRY MAKE UP OR SLAKING TANK _____

M. DISPOSAL OF SPENT LIQUOR

1. SCHEMATICS OF SLUDGE & FLY ASH DISPOSAL METHOD

(IDENTIFY QUANTITIES OR SCHEMATIC) _____

2. CLARIFIERS (THICKENERS)

NUMBER Two

DIMENSIONS 18'-6" ø x 27'

CONCENTRATION OF SOLIDS IN UNDERFLOW _____

3. ROTARY VACUUM FILTER

NUMBER OF FILTERS None

CLOTH AREA/FILTER _____

CAPACITY _____ TON/HR (WET CAKE)

CONCENTRATION OF SOLIDS IN CAKE _____

PRECOAT (TYPE, QUANTITY, THICKNESS) _____

REMARKS _____

_____

_____

4. SLUDGE FIXATION

POINT OF ADDITIVES INJECTION None

FIXATION MATERIAL COMPOSITION _____

FIXATION PROCESS (NAME) _____

FIXATION MATERIAL REQUIREMENT/TONS OF DRY SOLIDS OF SLUDGE

_____

ESTIMATED POND LIFE, YRS. _____

CONCENTRATION OF SOLIDS IN FIXED SLUDGE _____

METHOD OF DISPOSAL OF FIXED SLUDGE _____

INITIAL SOLIDIFICATION TIME OF FIXED SLUDGE _____

5. SLUDGE QUANTITY DATA

POND/LANDFILL SIZE REQUIREMENTS, ACRE-FT/YR _____

IS POND/LANDFILL ON OR OFFSITE On-site

TYPE OF LINER _____

IF OFFSITE, DISTANCE AND COST OF TRANSPORT _____

POND/LANDFILL DIMENSIONS AREA IN ACRES _____
DEPTH IN FEET _____

DISPOSAL PLANS; SHORT AND LONG TERM _____

_____

_____

_____

_____

N. COST DATA

1. TOTAL INSTALLED CAPITAL COST _____

2. ANNUALIZED OPERATING COST _____

4. COST FACTORS

a. ELECTRICITY _____

b. WATER _____

c. STEAM (OR FUEL FOR REHEATING) _____

d. FIXATION COST _____ $/TON OF DRY SLUDGE (pulverized limestone)

e. RAW MATERIAL PURCHASING COST 18 $/TON OF DRY SLUDGE

f. LABOR: SUPERVISOR _____ HOURS/WEEK _____ WAGE

OPERATOR _____ _____

OPERATOR HELPER _____ _____

MAINTENANCE _____ _____

O. MAJOR PROBLEM AREAS: (CORROSION, PLUGGING, ETC.)

1. SO_2 SCRUBBER, CIRCULATION TANK AND PUMPS.

a. PROBLEM/SOLUTION 1) erosion of 2" fibercast T at pump discharge. 2) flow control valve liner supposed to be teflon, but instead was carbon impregnated plastic, also rubber on rubber-lined pipes cracked/ 1 modified pipes, replaced T by 90° elbow and lowered velocity 2. rubber-lined piping changed and replaced control valve (butterfly) with teflon-lined valve. Cracking of rubber lining attributed to mfg. defects.

2. DEMISTER

PROBLEM/SOLUTION Essentially none
ΔP build up about 0.5" - 0.7" H_2O in
4 month period (12/15 - 4/2/74)

3. REHEATER

PROBLEM/SOLUTION 1) vibration due to size of duct vs. size of reheater transition duct, which caused harmonic vibrations (~40 mills deflection) 2) tube bundle leaking to acid condensation in uninsulated duct/ 1 installed baffles to break harmonics 2 replaced one tube bundle(out of 3)due to corrosion and installed diverted baffle to draw off acid condensations away from reheater tubes. duct upsteam of reheater was insulated.

4. **VENTURI SCRUBBER, CIRCULATION TANKS AND PUMPS**

PROBLEM/SOLUTION 1) Scaling on disc, buildup on shaft, hasn't caused a problem yet but might eventually bind shaft so it can't move. buildup in stuffing gland flange and on top of spray dome. 2) Pluggage of some small lines particularly when operating on reduced rates (lower flow velocity), also settling in stand by pumps/ 1 reversed packing gland position upside down, also removed one half of packing gland, didn't need that much.

5. **I.D. BOOSTER FAN AND DUCT WORK**

PROBLEM/SOLUTION 1) vibration problems due to accumulation of scale buildup while fan was idle / 1 cleaned fan and sandblasted it.

6. **LIMESTONE MILLING SYSTEM OR LIME SLAKING**

PROBLEM/SOLUTION N/A

7. **SLUDGE TREATMENT AND DISPOSAL**

PROBLEM/SOLUTION No problem

8. **MISCELLANEOUS AREA INCLUDING BYPASS SYSTEM**

PROBLEM/SOLUTION Vertically mounted valves (stem horizontal) scale and sediment buildup in dead space. Modified valve position to horizontal piping and installed wash out lines. Have 20 Hilton valves. They were the only ones that caused problems in vertical position.

P. **DESCRIBE FACTORS WHICH MAY NOT MAKE THIS A REPRESENTATIVE INSTALLATION** treatment of sludge is understood not to be required due to high rate of evaporation in Arizona. Method presumed acceptable to Local EPA. 1) Lack of limestone milling facilities (APS plans to install such system when other two boilers are in operation and FGD system installed 2) Absence of sludge treatment & fixation may not be acceptable in other locals.

Q. **DESCRIBE METHODS OF SCRUBBER CONTROL UNDER FLUCTUATING LOAD. IDENTIFY PROBLEMS WITH THIS METHOD AND SOLUTIONS. IDENTIFY METHOD OF pH CONTROL AND LOCATION OF pH PROBES.**

R. CLASSIFY WATER LOOP MODE OF OPERATION

Since no water is recycled to the FGD system from the pond, the installation is considered to be operating under completely open water loop conditions.

APPENDIX B

PLANT PHOTOGRAPHS

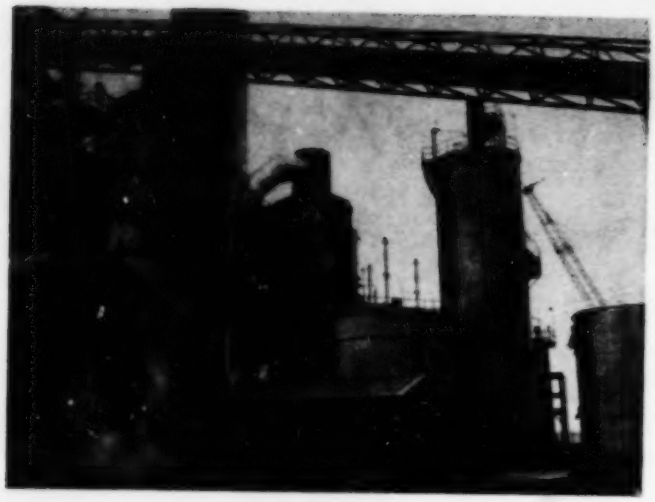


Photo No. 1 General view of the flue gas desulfurization facilities at the Cholla Power Station. The facilities consist of two parallel SO_2 scrubbing trains (shown on left) with a common slurry circulation tank (center). The pulverized limestone is stored in the tall silo shown to the right of the slurry circulation tank. Part of one of the two sludge holding tanks can be seen behind the limestone silo. The electrical switch gear and part of the control instruments are housed inside the building shown in the center.

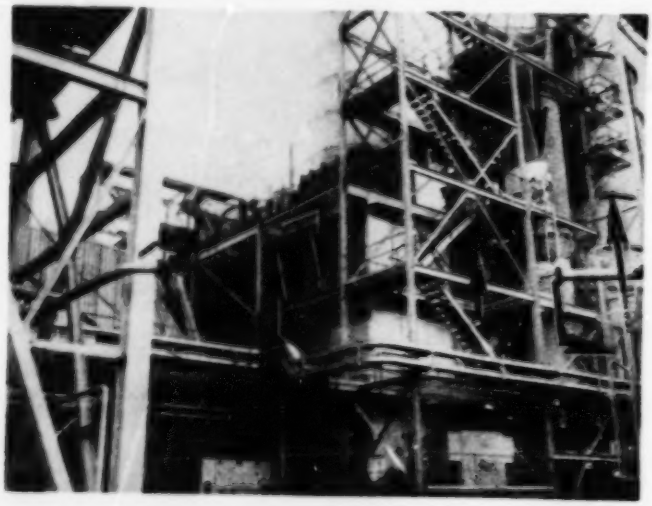


Photo No. 2 Back view of SO_2 scrubbing train A, showing flue gas ductwork to the boiler I.D. fan and the booster I.D. (to the right) as well as the flooded-disc scrubber and the SO_2 absorber tower (at extreme right). The path of flue gas through equipment is indicated by arrows.

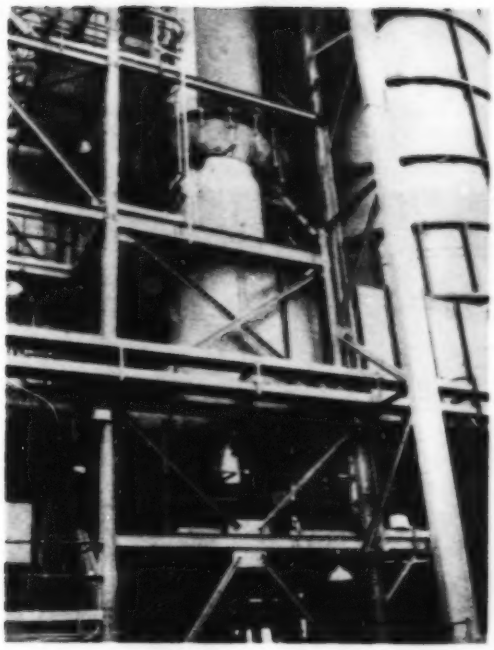


Photo No. 3 Close up view of the flooded-disc scrubber. The cluster of pipes around the throat of the scrubber distribute the limestone slurry to nozzles located in the walls of the scrubber vessel near the entrance to the throat. Limestone slurry also enters at the base through the scrubber shaft to the flooded disc near the throat.

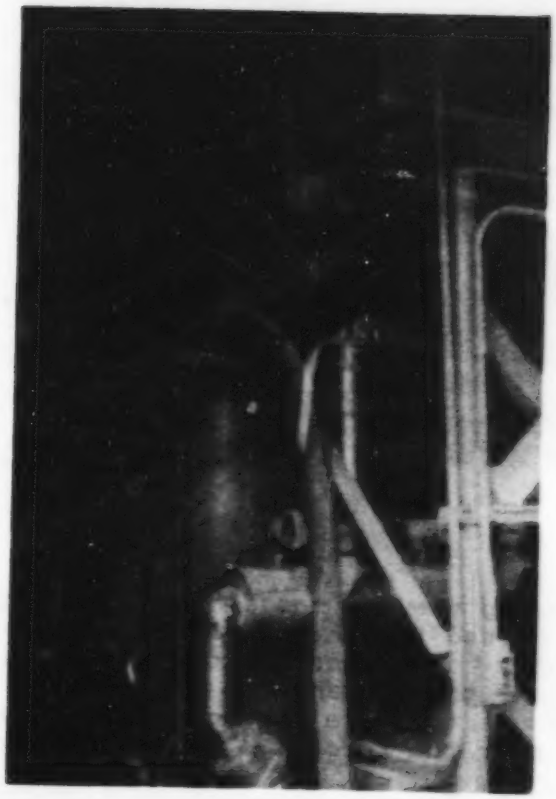


Photo No. 4 Inside view at the base of the limestone silo. The limestone vibrating hopper is on top of the structure and feeds controlled quantities of limestone to the slurry mix tank below.

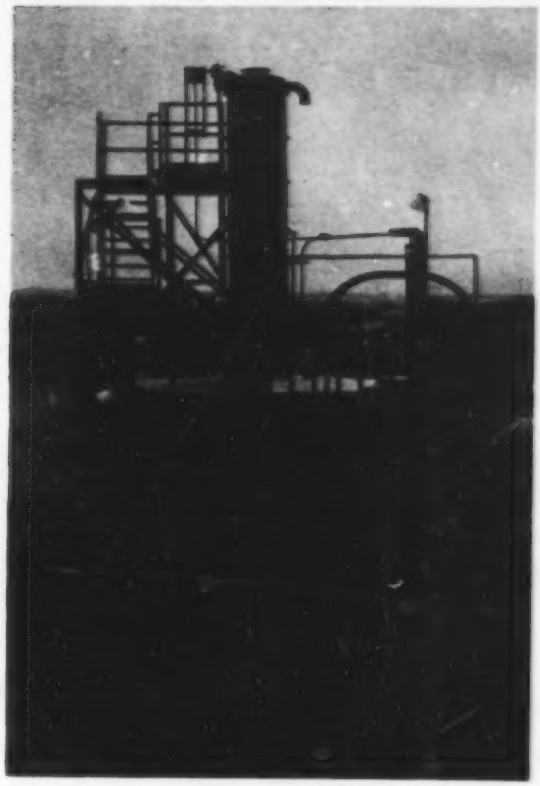


Photo No. 5 View looking south towards upper half of the limestone silo showing the pneumatic charging line. The vertical limestone dust trap is on the top of the silo.

Photo No. 6 View from top of the boiler structure looking towards SO_2 scrubbing train A. The picture shows the insulated duct from top of the absorber tower to the reheater unit. Part of the concrete stack appears to the left.

Photo No. 7 View from top of the boiler structure looking towards SO_2 scrubbing train B. The equipment layout of this train is a mirror image of that of train A.

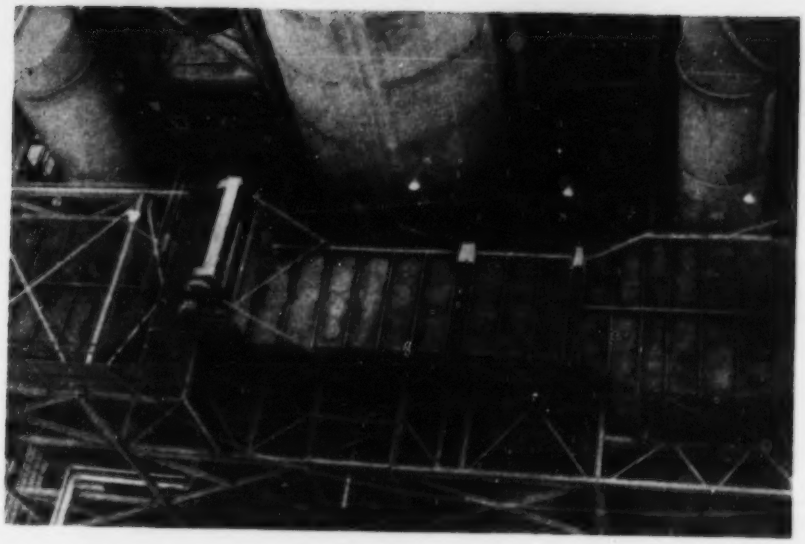


Photo No. 8 View from top of the boiler structure looking towards the area between the two SO_2 trains. The reheaters of both trains are shown on opposite sides of the common concrete stack. In the center of the picture is the common suction ductwork for both booster fans. A motorized bypass sliding vane-type of valve is shown center-left portion of the picture.

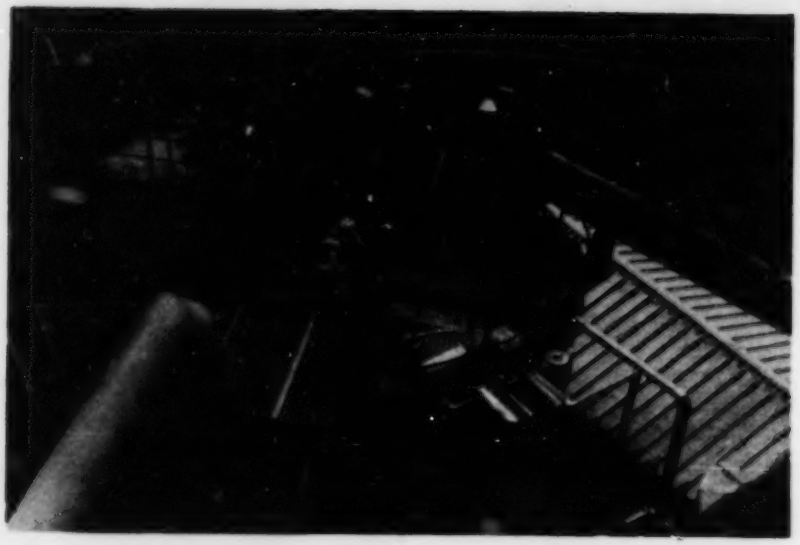


Photo No. 9 Top view of the common slurry circulation tank which serves both trains. The return piping from both absorber towers can be seen on opposite sides of the tank. The tank agitator motor and gear are in the center.

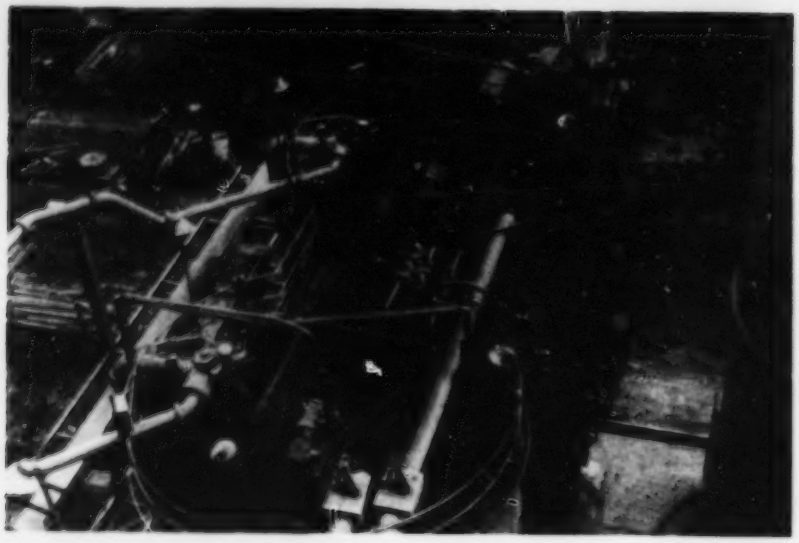


Photo No. 10 Top view of the twin sludge holding tanks showing the feed lines from both flooded-disc scrubbers to each sludge tank. The discharge from the sludge tanks to the disposal pond is intermittent and through pipes which are also used for sluicing of fly ash to the pond.

Photo No. 11 View of battery of SO_2 absorber tower feed pumps. There are three feed pumps: two are in operation serving both towers through a common discharge header and the third is a standby.

Photo No. 12 View of the main instrument panel located in the powerhouse main control room. The panel contains key instruments and alarms for remote control of the flue gas desulfurization equipment.

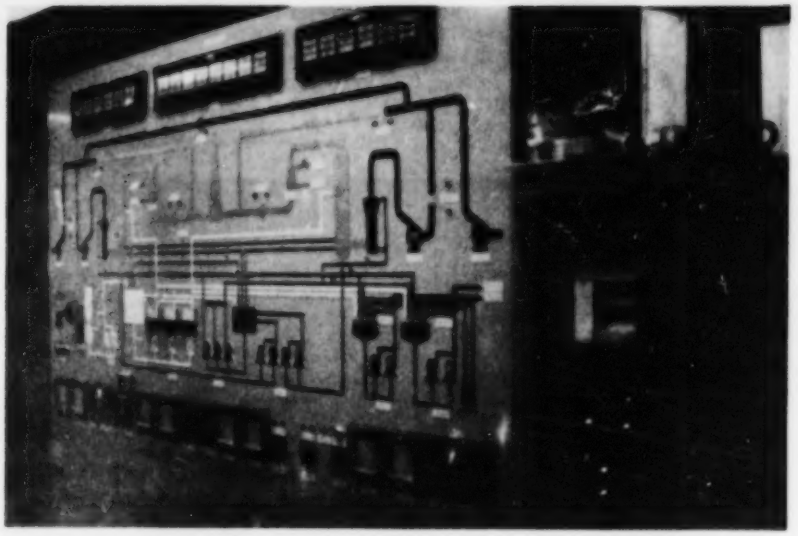


Photo No. 13 View of the auxiliary control panel located in the electric switch gear building. The panel shows a schematic flow diagram of the installation and contains mostly recording instruments. DuPont's SO_2 analyzer which records the concentration of SO_2 into and out of the FGD system is shown to the right of the instrument panel.

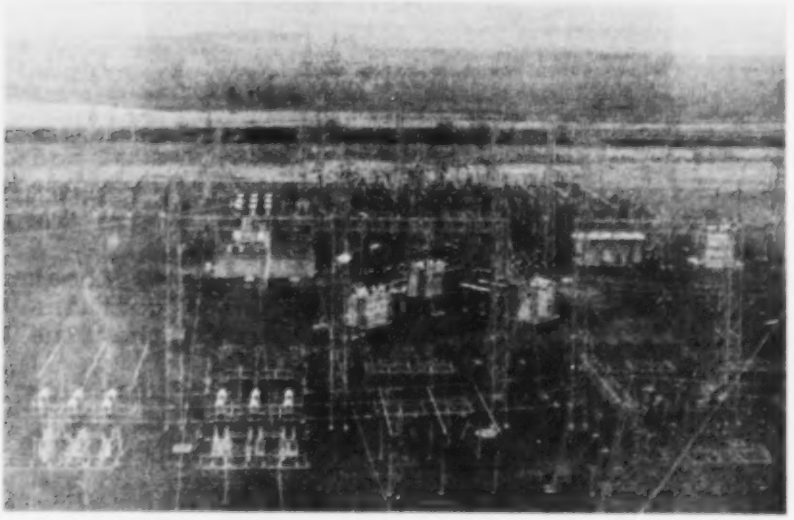


Photo No. 14 View from top of the boiler structure looking south towards the transformers switchyard. The railroad cars which deliver coal to the plant can be seen immediately behind the switchyard.

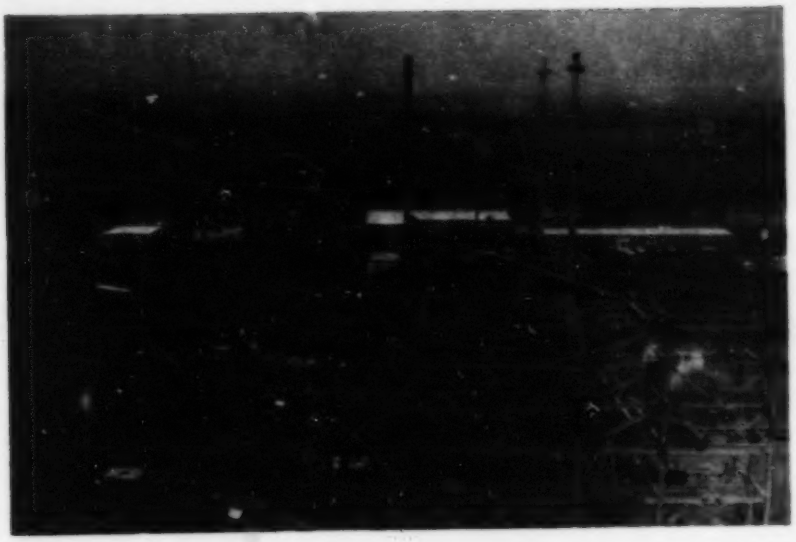


Photo No. 15 View from top of the boiler structure looking west towards the structure of boilers 2 and 3, which are presently under construction. The concrete structures to the left are the concrete foundations for the steam turbines and generators for each boiler.

Photo No. 16 View from top of the boiler structure looking southeast towards the sludge and fly ash disposal pond located behind the railroad tracks. The lake shown in the foreground provides fresh water to the plant. The slurry pipe can be seen near the edge of the lake.

APPENDIX C

OPERATING DATA

Table C-1 RESULTS OF FGD SYSTEM TEST RUNS OF OCTOBER 1973[a]

Data	Side A	Side B	Stack
Particulate concentration inlet (gr/SCFD)	1.995	2.537	-
Particulate concentration outlet (gr/SCFD)	0.0083	0.0101	0.1149
SO_2 concentration outlet (PPM)	34	357	236
SO_2 concentration inlet (PPM)	417	409	-

Data	"A" Side	"B" Side with Ring	"B" Side without Ring
SO_2 removal (percent)	92.4	14.4	9.2
Particulate removal efficiency (percent)	99.7	99.8	99.7
Gas inlet to FDS (ACFM @ T=276°F, P=27.3"Hg)	214,300	204,600	240,300
Theoretical inlet gas to FDS (ACFM)	198,800	198,800	-
Apparent bypass leakage (ACFM @ T=276°F, P=27.3"Hg)	16,900		-
FDS L/G ratio (gal./1000 ft^3)	10.1	10.6	5.8
Tower L/G ratio (gal./1000 ft^3)	48.9	0.0	0.0
Gas velocity through tower (ft/sec)	6.9	6.6	7.7
Mist entrainment from tower (gr/SCFD)	0.000	0.000	N.A.
Solids entrainment from tower slurry (gr/SCFD)	0.005	N.A.	N.A.
Pressure drop FDS (IWG)	14.8	15.7	13.5
Pressure drop tower demisters (IWG)	0.00	0.00	-
Pressure drop reheater (IWG)	5.15	2.30	-

[a] Reported by Research-Cottrell.

Table -1 RESULTS OF FGD SYSTEM TEST RUNS
OF OCTOBER 1973 (continued)

Data	"A" Side	"B" Side with Ring	"B" Side without Ring
Temperature tower outlet (°F)	121	121	121
ΔT reheater (°F)	65	60	60
Demister water rate (GPM)	12.2	14.0	14.0
Slurry flow to FDS (GPM)	2170	2177	1400
Slurry flow from FDS (GPM)	1317	1486	N.A.
Limestone feed rate (lb/min)		16.6	
Slurry flow from tower tank to FDS tank (GPM)		32.5 (est.)	
Slurry flow from FDS tank to slurry (GPM)		64.0	
Tower tank makeup water (GPM)		0	
FDS tank makeup water (GPM)		N.A.	
Specific gravity/percent solids tower tank		1.049/8.3	
Specific gravity/percent solids FDS tank		1.102/14.8	
Percent solids FDS tank (be Dynatrol)		15.5	
Tower tank pH		6.5	
FDS tank pH		5.2	
Coal consumption (tons/hr)		54	
Coal heating value (BTU/lb)		10,293	
Atmospheric pressure (in. Hg)		25.3	